

THE HII REGIONS IN M51: RADIO AND OPTICAL OBSERVATIONS

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ABSTRACT. High resolution, dual frequency radio observations and calibrated H_α surface photometry of the spiral galaxy M51 are used to determine the physical properties of the 40 brightest HII region complexes. M51 appears to have a normal HII region population when compared with other nearby Sc galaxies for which good data exist. We used the radio and H_α data to measure the extinction toward the HII regions. The extinction is very patchy but appears to have a weak trend to become on average smaller toward large galactocentric radii. This trend is consistent with a possible metallicity gradient in M51. We compared the radio determined extinctions with Balmer decrement extinctions and found good agreement between the two, contrary to previous studies of M51 and other galaxies.

1. INTRODUCTION

Several observable properties of galaxies provide information about recent, massive star formation. Each of these, however, has its drawbacks. The far infrared emission, for example, measures not only the energy absorbed by warm dust around HII regions, but also represents emission from cool dust illuminated by the interstellar radiation field. (Cox and Mezger, this volume, Persson and Helou, this volume). These components are difficult to separate so that an assessment of the massive star formation rate is difficult. A similar problem exists when one tries to measure the thermal radio emission from HII regions. The thermal free-free emission in principle measures all ionizing photons. The usual observational handicap, however, is that the thermal radio emission one measures is contaminated with non-thermal emission from the underlying disk and spiral arms, so that here also one cannot simply use the total radio emission from the HII regions as an indicator of the ionizing photon flux. First the thermal and non-thermal emission must be separated. A third way of measuring star formation is to observe the H_α emission. The prime difficulty with this method is that one needs to correct the H_α emission for the extinction, which is often not well known.

We have used dual-frequency radio maps and calibrated H_α surface photometry to investigate the distribution of extinction and to study the HII region population in the spiral galaxy M51. The radio maps allowed us to measure the free-free emission from the HII regions so that it is possible to estimate the extinction by comparing the free-free radio emission with the H_α emission of the same region. The exact procedures and results will be discussed briefly in the next two sections.

2. OBSERVATIONS

The radio observations were obtained with the Very Large Array (VLA) of the NRAO² in 1981-1982. (for details see Van der Hulst et al. 1987). The maps used for this study are maps at 6 and 20 cm wavelength obtained from the multi-array data which have a resolution of 8" (372 pc at the 9.6 Mpc distance of M51). This resolution appeared best for detecting the most HII regions. The reason is that some of the lower surface brightness regions begin to resolve out at higher resolution.

The H α data were obtained with the two stage Carnegie Image tube on the KPNO 2.1 m telescope. Two plates, one at H α and one in the red continuum were scanned on the KPNO PDS microdensitometer, calibrated, and then subtracted. The resulting H α emission image was then smoothed to 8" resolution to match the radio resolution. The H α data were calibrated using spectrophotometric data taken with the IDS scanner on the UCSD-UM 60" telescope at Mt. Lemmon. Spectrophotometry was obtained through 9" apertures for 15 HII regions (for a detailed description see Van der Hulst and Kennicutt 1987).

The radio maps and H α map were interpolated onto a common grid and then blinked to identify the HII regions which have been detected in both data sets. The radio data are essentially noise limited and restrict the number of regions that can be identified and used. We detected 32 regions at H α and in the radio and found another 8 with probable detections in the radio. These are the 40 brightest HII regions in M51. We then measured fluxes at 6 and 20 cm in the radio and in H α through circular apertures varying in diameter from 12" to 21" depending on the extent of the region. A correction for background emission was made as described in Van der Hulst and Kennicutt (1987). The 6 cm radio fluxes were decomposed into a thermal and a non-thermal contribution assuming a non-thermal spectrum with a slope of $\alpha = -0.9$ ($S \propto \nu^\alpha$), as indicated by the total, largely non-thermal emission of M51 (Klein and Emerson 1980). About half of the HII regions have 6 cm fluxes which are entirely thermal. For the other regions the fraction of thermal emission at 6 cm varies from 50 to 80 %. The extra non-thermal emission is probably due to small scale structure in the underlying disk or objects like supernova remnants. It should be pointed out that supernova remnants, and in particular young supernovae, may have a flat radio spectrum (Reynolds and Chevalier, 1984) and are therefore inseparable from the thermal emission of the HII regions. We then used standard recombination theory to calculate HII region properties (following Schraml and Mezger 1969) and the extinction in the visual (A_V). For these calculations we assumed an electron temperature of 7000 K, based on the average excitation of the HII region spectra. (see also McCall et al., 1985)

3. RESULTS

The HII region properties as determined from the radio fluxes are quite normal and not drastically different from earlier results in M51 (Israel, 1980) or recent results on the HII region population in M33 (Viallefond and Goss, 1986). Electron densities typically range from $2 - 5 \text{ cm}^{-3}$, HII masses are $3 - 8 \times 10^6 M_\odot$ and the emission measures are $10^3 - 10^4 \text{ cm}^{-6} \text{ pc}$. The excitation parameter ranges from 350 to 700 which indicates the equivalent of 20 to 150 O5 stars required to ionize the HII regions. The large number of radio detections enables us to construct the HII region luminosity function more reliably than in the past. Figure 1 shows both the radio and the H α luminosity function for the HII

regions we detected. The two luminosity functions are fairly similar and agree quite well with the radio luminosity function Kaufman et al. (1987) find for the HII regions in M81. Israel (1980) found a much steeper luminosity function for M51. This is almost certainly a result of the large errors in his fluxes for the HII regions due to the low resolution and low sensitivity of the data he used.

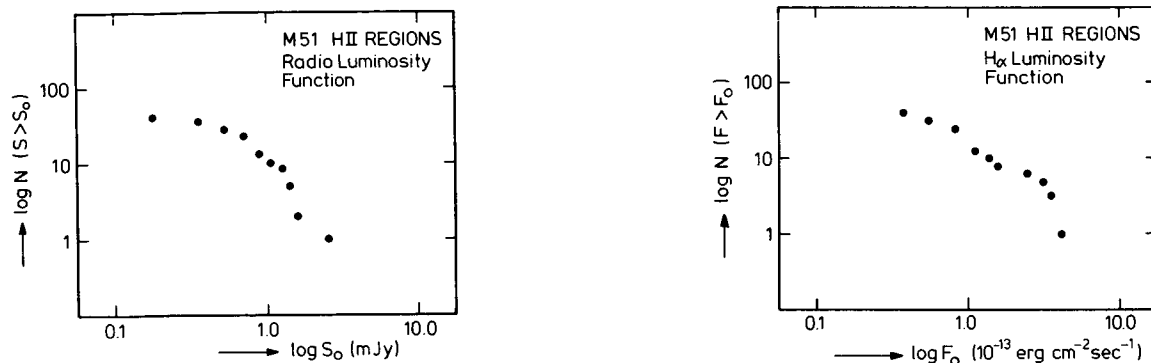


Figure 1. Radio luminosity function (left panel) and H_{α} luminosity function (right panel) of the HII regions in M51.

We can use the radio and H_{α} data to probe the extinction in the direction of the HII regions to give us some idea of the variation of extinction within the galaxy. The extinctions found vary from $A_V = 0.4$ to 4 magnitudes with a median value of $A_V = 1.8$. The extinction appears to be very patchy. An extreme example is 3 neighbouring HII regions in the eastern spiral arm where we find $A_V = 2.8, 0.7$ and 2.5 respectively. Although the spread in extinction is quite large there appears to be a slight trend toward lower extinction at larger galactocentric radii. Figure 2 illustrates this trend. The inner two points and the outermost point are based on single measurements and therefore placed between parentheses.

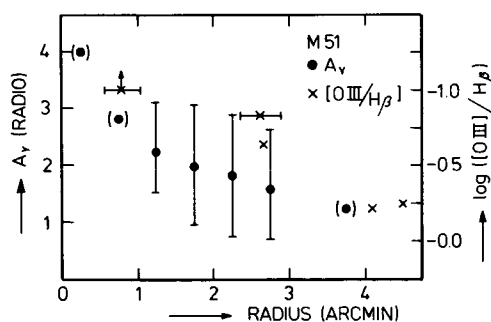


Figure 2. Radial dependence of A_V in M51. The excitation gradient in M51 is indicated by the crosses.

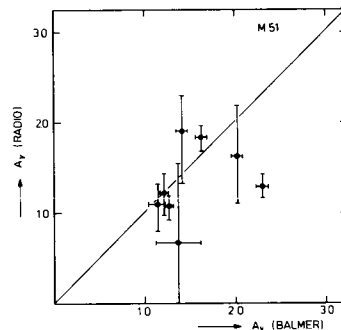


Figure 3. Comparison of A_V as determined from the Balmer decrement and A_V as derived from the radio - H_{α} flux ratios.

There nevertheless appears to be a slow decrease in average A_V when going from a radius of 1 to 3 arcminutes. This trend is in the same sense as the $[OIII]/H_{\beta}$ excitation gradient found by Smith (1975) (plotted as crosses in Figure 2), and indicates that the extinction gradient is probably related to a metallicity gradient in M51.

It has been shown in the past that extinctions determined using the radio - H_α comparison method as described above are systematically larger by on average 1.2^α magnitudes than extinctions derived from the Balmer decrement (Israel and Kennicutt 1980). Two ways to account for this are absorption internal to the HII regions or heavy clumping of the absorbing material inside or in front of the HII regions. Since we have Balmer decrements from the Mt. Lemmon spectrophotometry for 15 HII regions of which 8 overlap with the radio sample we can investigate this further in M51. Figure 3 shows the 8 regions with A_V determined from both the Balmer decrement and the radio - H_α comparison. For these regions one would conclude that both methods agree well and that no systematic difference exists. Recent work by Caplan and Deharveng (1986) in the Large Magellanic Cloud indicate that there a systematic difference exists of only 0.3 magnitudes, also much less than found in the past for galaxies in general. Requirements for internal and/or clumped extinction are therefore much milder. Caplan and Deharveng (1986) discuss various geometries for the dust distribution and suggest that the extinction is a combination of mostly general interstellar dust, partly clumped, and some scattering dust in and around the HII regions.

4. ACKNOWLEDGEMENTS AND NOTES

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